ORIGINAL ARTICLE

Occupational noise exposure and ischaemic heart disease mortality

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Aims: To investigate the hypothesis that long term exposure to excessive noise can increase the risk of ischaemic heart disease.

Methods: A case-control design, nested within a cohort of nuclear power workers employed at two sites in England over the period 1950–98, was used. Cases were men who died from ischaemic heart disease (ICD-9: 410–414) aged 75 or under; each was matched to a surviving control of the nearest age who joined the same site at the same time. Personal noise exposure was assessed retrospectively for each man by hygienists using (1) company work histories, (2) noise survey records from 1965–98, and (3) judgements about likely use of hearing protection devices. Men were classified into four groups according to their cumulative exposure to noise, with men whose exposure at the company never exceeded 85dB(A) for at least one year being considered ''unexposed''. Risks were compared via odds ratios (ORs) using conditional logistic regression and adjusted for systolic and diastolic blood pressure, height, BMI, and smoking, as measured at recruitment to the company.

Results: Analysis was based on 1101 case-control pairs. There was little difference between the exposure groups at recruitment. There was no evidence of increased risk at site A: the ORs for ischaemic heart disease mortality among low, medium, and high exposure categories, compared to unexposed men, being 1.04, 1.00, and 0.77. The corresponding ORs (95% CIs) at site B were 1.15 (0.81–1.65) 1.45 (1.02–2.06), and 1.37 (0.96–1.96). When the comparison was confined to men with at least five years of employment, these dropped to 1.07 (0.64–1.77), 1.33 (0.88–2.01), and 1.21 (0.82–1.79) respectively.

Conclusions: The authors did not find statistically robust evidence of increased risk but the estimates at site B are consistent with those in a major cohort study. A strength of the present study is that the validity of noise estimation at site B has been demonstrated elsewhere.

Excessive noise, at work or in the wider environment, has been linked with increased blood pressure and risk of ischaemic heart disease. A meta-analysis[1] of nine cross sectional, ''well matched'' occupational studies concluded that an increase of 5dB(A) on the 8-hour A-weighted scale was associated with an increase of 0.51 mmHg (95% CI 0.01 to 1.00) in systolic blood pressure and of 14% (1%–29%) in the prevalence of hypertension. However, the authors noted that the results of the studies were inconsistent and there was some evidence of a publication bias against small negative studies. An earlier review of occupational exposure[2] concluded that there was considerable evidence that noise has short term effects on cardiovascular function and catecholamine levels but that, although there was a suggestion that chronic noise exposure might lead to sustained increases in blood pressure, there was a lack of convincing evidence that it caused cardiovascular disease. This was, in part, due to poor quantification of noise exposures and inadequate consideration of confounders.

Another problem is that there have been few longitudinal studies: although some of the reviewed studies incorporated estimates of cumulative exposure, they were essentially cross sectional with the emphasis on prevalence. One longitudinal study[3] of miners with high exposures who remained in work for at least 10 years found no evidence of a link with blood pressure. Lang *et al*[4] found effects on blood pressure only among those exposed at work to levels above 85dB(A) for at least 20 years, but there may have been insufficient power at lower durations. Recently, the findings from a large cohort study[5] of lumber mill workers, including workers with 20 or more years at levels over 85dB(A), have been reported. Among workers who terminated employment before the introduction of hearing protection devices, there was a exposure-response relation between ischaemic heart disease mortality and years of exposure above 85dB(A), with a relative risk of 1.3 ($p = 0.04$) in those with 20 or more years' exposure above 85dB(A) compared to less than three years, after adjustment for age, calendar year, and ethnicity. Twenty or more years above 95dB(A) produced an RR of 1.5 (95% CI 1.1 to 2.2).

According to the Netherlands Health Council committee on Noise and Health, the ''no adverse effect level'' for industrial workers is at most 85dB(A) on the 8-hour A-weighted scale and, for general environmental noise, 70dB(A) on the 24-hour L_{dn} scale.[6 7] A large cohort study[8] of road traffic noise and incidence of ischaemic heart disease found no statistically significant effects, perhaps because the maximum L_{dn} was less than 70 dB(A). On the other hand, a recent, large case-control study[9] found an OR of 1.8 (95% CI 1.0 to 3.2) for myocardial infarction among men who lived for at least 10 years in homes with daytime traffic noise levels above 70dB(A). Other cross sectional studies[10 11] found a relation between aircraft noise, up to 76dB(A) on the L_{dn} scale, and use of medication for cardiovascular diseases.

Given these results and the ubiquity of noise exposure, there is a need for further longitudinal studies. We report here on a longitudinal study of occupational exposure and mortality from ischaemic heart disease among a cohort of nuclear power workers in England.

Abbreviations: BMI, body mass index; BP, blood pressure; NIL, noise immission level

METHODS

Subjects

A nested case-control design was used for reasons of economy. The study cohort was defined as all males who started ''industrial work'' at either of two rural sites (referred to here as site A and site B) of the same company, while aged 50 years or under between 1 January 1950 and 31 December 1998, and who worked there for at least one month. Work at the sites included nuclear power production, reprocessing nuclear fuel, manufacture of nuclear fuel rods, and light engineering. Industrial workers comprised those directly involved in production, manual skilled, and unskilled workers who were indirectly associated with production (for example, painters, joiners, storemen), and excluded professional, technical, and administrative staff. In the course of the study, a small number of subjects were found to have started work in the 1940s; these were retained in the analyses.

Under an existing agreement between the company and the Office of National Statistics for England and Wales, all deaths among study population members had already been notified to the company, together with cause of death coded to (Internation Classification of Diseases) ICD-8 or ICD-9 depending on year of death. The 1220 cohort members who died from ischaemic heart disease (ICD-9 codes 410–414) at age 75 years or under between 1 January 1950 and 31 December 1998 formed the case group for the present study. For each case a control, who was alive at the time of the case's death, was chosen from cohort members at the same site, matched as closely as possible on age and year of starting work, with a maximum difference of three years being allowed on these variables.

Assessment of noise exposure

Anonymous work histories for each subject, consisting of building numbers and job titles throughout employment, were extracted by company personnel from workplace records and given to the study team. All relevant information from three sources—personnel, the occupational health department, and the radiation dosimetry department—was extracted. Personnel data were generally the most complete, giving, for each man, start and end dates for consecutive periods of work during which job title and building were said to be fixed. If other sources suggested that place of work or job title was not fixed within any such period, a further split into two or more periods was made. Where there were discrepancies between the three sources of information in terms of buildings, dosimetry department records were considered the most reliable; information from other sources was used to fill any gaps in their record. In some cases, buildings were described in words rather than by a number, and some of these had shut down or undergone a change of function. To help translate text into building numbers, needed for linkage with noise survey records, retired and long term employees of the company familiar with the sites were consulted; nevertheless numbers could not be assigned in some instances. If the job title for a particular period was missing, but job titles in the periods immediately preceding and immediately following were identical, then the same job title was assigned to the intervening period.

Employment information from all subjects was aggregated, for each site separately, to give a list of all the combinations of building × job title × year for which noise estimates were required. Estimates of the $L_{EP,d}$, that is, 8-hour average daily personal noise exposure, measured in decibels on the A-weighted scale (dB(A)), were made for each combination by a team of three occupational hygienists who were unaware of whether the histories related to cases or controls.

The methods used by the hygienists are described in full elsewhere.[12] The company had carried out noise monitoring surveys since 1965. Survey reports, from 67 buildings of interest at site A and 89 buildings at site B, were made available to the hygienists, and included about 4590 sound pressure measurements at site A and 832 at site B. These were mainly hourly measurements but also included some one minute readings (15%) and personal dosimetry measurements (5%). Using these reports, two of the hygienists independently estimated noise exposures for each combination of building × job title × year. If their separate estimates for a given combination differed by 5dB(A) or less, the midpoint was taken as the final estimate. If they differed by 6 to 10 dB(A), a third hygienist provided an additional independent estimate; the median of the three estimates was then taken as the final estimate. If any two estimates differed by more than 10 dB(A), the three hygienists met to reach a consensus. Where noise surveys did not cover the whole period of interest for a building, extrapolations were made from other periods after considering the possibility of time trends in exposure.

Some buildings did not have noise surveys; also building number was unknown for parts of some subject histories. To fill these gaps, noise estimates were constructed based on additional rules using job title and site of work only. For each combination of site and job title separately, noise estimates from surveyed buildings were aggregated and the median level found, after weighting estimates by the number of study subjects in each building. These medians were used as the estimates, except if they implied a noise exposure above 80dB(A) for a building in existence after 1965 but never surveyed. In this case, the value was reduced to 80dB(A) on the grounds that if noise levels had been higher, company hygienists would have carried out a survey. If there was no job title, no estimate of noise exposure was made.

A hearing protection questionnaire (Burgess *et al*,[12] p. 126, Table A2) was used to elicit information, about likely use and type of personal protective equipment, from long term employees or retired workers whose jobs required them to visit many parts of the sites. The hygienists then defined a set of rules by which the above environmental noise exposure estimates were to be reduced to give personal exposure estimates. Exposure estimates for years before 1960 at site B, and before 1975 at site A, were left unchanged. Reductions were made to exposures over 90dB(A), for selected buildings at site B during 1960–74 and from 1974–90 for all buildings at both sites. These were generally small (1 or 2dB(A)) reflecting a judgement that hearing protection might not have been used, or not used appropriately before 1990. From 1990 onwards, all exposure estimates over 90dB(A) were reduced to 90dB(A).

Classification of subjects by noise levels

For each subject, the complete exposure history consisted of a series of time periods of varying length, T, within which the 8-hour personal noise exposure, E, was assumed constant. The threshold for any adverse effect of noise on long term cardiovascular risk was assumed to be one year at 85dB(A): men estimated to have less than one year's exposure at a level of 85dB(A) or higher were classified as ''unexposed''.

Three indices of exposure—TT_{85}, M_{85}, and NIL_{85}—were calculated for other subjects. TT_{85} was the total years with estimated noise exposure above 85dB(A), while M_{85} and NIL_{85} were measures of average and cumulative intensity over time. If exposure estimates were missing for part of a subject's employment, TT_{85} was imputed by assuming that the proportion of their employment with $E \geqslant 85$dB(A) was equal to the observed proportion during periods with estimates. The mean, M_{85}, measured in dB(A), was based

on periods with E ≥85dB(A) only, and was calculated as follows. For each such period, the noise intensity, I (watts/m^2) was calculated from E by $I = 10^{-12}*(10^{E/10})$, and multiplied by the number of years, T. The cumulative intensity, ΣIT, and the mean intensity $\Sigma IT/TT_{85}$, across these periods was found. M_{85} was calculated from mean intensity using the reverse transformation. If exposure estimates were missing for part of a subject's employment, M_{85} was based only on periods with estimates. The measure of cumulative exposure, the noise immission level (NIL),[13] could in theory be calculated by applying the same transformation to cumulative intensity. Here it was calculated using the equivalent formula, $NIL_{85} = M_{85}+10*\log_{10}(TT_{85})$, as this approach automatically took account of periods with missing data.

Categories of NIL_{85} were created using cut-off points which divided the exposed subjects into roughly three equal sized groups, with values in the ranges (85–94.7), (94.8–99.6), and (99.7–109.6)dB(A)-years. The NIL_{85} scale assumes that, for example, four years exposure at 91dB(A) is the same as eight years at 88dB(A) or 16 years at 85dB(A).

The predictive validity of the measures TT_{85}, M_{85}, NIL_{85} has been investigated in a separate study[14] of their relation with hearing loss. A exposure-response relation was observed between hearing loss and NIL_{85} among workers at site B and there was evidence that both TT_{85} and M_{85} were separately predictive. No relation was seen at site A.

Measures of potential confounders

All subjects had a pre-employment medical assessment and annual examinations while employed, which measured blood pressure (BP), weight, and height, and recorded smoking habit. Only variables from the pre-employment examinations were considered as potential confounders, as changes over the course of employment, for example in blood pressure, might be an effect of exposure to noise and thus an intermediate variable on the causal pathway of interest. Information on weight, height, and BP at pre-employment was fairly complete but where either of these or smoking at pre-employment was missing, it was imputed from the next medical examination with relevant data. Body mass index (BMI) was calculated as weight in kilos divided by the square of height in metres. Information on smoking habit was not routinely recorded until later years and therefore for some subjects, no pre-employment classification, imputed or otherwise, was possible. Information was available on whether subjects worked shifts during employment and was used to classify each worker according to whether or not he had worked shifts for a month or more.

Table 1 Employment characteristics of 1101 cases and 1101 controls

	Cases	Controls
Age at start of employment (years)		
Mean	37.2	37.1
Median	37.7	37.7
SD	8.4	8.4
Range	15–50	15–50
Year of recruitment		
Mean/median	1957	1957
Range	1946–91	1946–91
Duration of employment (years)		
Mean	11.5	12.5
Median	9.7	10.6
SD	9.7	10.7
Range	1 month–40 years	1 month–40 years
Age on leaving* (years)		
Mean	49.1	50.0
Median	50.9	51.7
SD	12.6	13.7
Range	20–65	17–66

*Some individuals were employed for two or more separate periods; hence the mean age at leaving is longer than the sum of the mean at start and mean duration of employment.

Statistical analysis

The employment history of controls was censored at the time of death of their matching case if necessary, and measures of noise exposure calculated from the preceding period only. Odds ratios (ORs) associated with the various indices of exposure were estimated using a conditional logistic regression model which also included smoking habit, BMI, height, systolic BP, and diastolic BP as recorded at the pre-employment medical examination. Systolic and diastolic blood pressures, BMI, and height were represented as continuous variables in the regression models. Smoking status was categorised as non/ex-smoker, 1–9 per day, 10–19 per day, and 20+ per day, and unknown. Both categorical and continuous indices of exposure were examined in different models. Tests for trends of increasing risk with increasing levels of exposure in the exposed subgroup alone were based on continuous exposure measures but with the dichotomous variable (exposed/not exposed) also included in the same model. As discussed below, the possibility that duration of employment might act as a confounder was considered and it was included in some models classified in five-yearly intervals. In an alternative approach, estimates of noise effects were based only on comparisons among those with at least five years employment at the company.

Statistical power

Power calculations were based on a hypothetical study population with only two exposure categories, ''low'' and ''high'', and half of the population in the high category. If high exposure increased risk by 30% (40%) (50%), then a nested case-control study in such a population, based on 550 cases and 550 controls, would have 56% (78%) (91%) power to find a statistically significant result, using a two-sided test and a 5% significance level. Although the actual study was almost twice this size, these power considerations are relevant to a comparison of the highest and lowest quartiles of the exposure distribution.

RESULTS

There were 1220 deaths from ischaemic heart disease, 569 from site A and 651 from site B. Ten per cent (n = 119) of the 1220 case-control pairs were omitted from the analyses due to missing information: there was no information on noise levels during employment for 11 subjects (five cases, six controls) and a further 120 subjects (63 cases, 57 controls) had no information on either height, blood pressure or weight. Because of the ''paired'' nature of the statistical analyses, both subjects with missing data and their pair match had to be omitted from analysis, leaving 1101 pairs with complete data. Omissions were greater at site B (15%) than site A (4%), and for those with shorter employment: 14% of those employed less than five years were omitted versus 7% of the remainder.

The median age at death of the cases was 63 years (range 29–75 years). Twenty per cent of cases died while still employed by the company, while 30% died more than 20 years after leaving. The majority of cases began work at the company in the period 1950–69, with a median age at the start of employment being 37 years. Length of employment varied considerably: the median was 9.7 years, but 23% were employed for less than two years and 23% were employed for 20 years or more.

Controls and cases were very similar as regards age at start of employment and year of recruitment (table 1), reflecting

Table 2 Baseline cardiovascular factors and employment characteristics by exposure group (controls only)

	Cumulative exposure, NIL_{85}			
	Unexposed* (n = 416)	Low* (n = 232)	Medium* (n = 220)	High* (n = 233)
Age at recruitment (median years)	36	38	39	38
Height (median cm)	171	171	171	170
High blood pressure at recruitment (% with BP⩾160 and/or DBP⩾95)	23%	19%	20%	25%
Overweight at recruitment: (% with BMI >25)	31%	28%	30%	29%
Smoking				
(1) % smokers among those with smoking data	67%	70%	69%	66%
(2) % missing	42%	31%	13%	2%
Shiftwork				
(1) % ever among those with data	50%	59%	70%	74%
(2) % missing	7%	8%	3%	3%
Employment duration (median years)	2	3	13	21

*Unexposed, less than one year above 85dB(A); low, $85 \leqslant NIL_{85} < 94.8$; medium, $94.8 \leqslant NIL_{85} < 99.7$; high, $NIL_{85} \geqslant 99.7$.

the matching in the study design. The median length of employment among controls (10.6 years) was about a year longer than for cases, but when coverage of employment of controls was censored at the date of death of the matching case, the median for controls (8.6 years) was less than for cases (9.7 years).

Over 1500 building × job title combinations were assessed by hygienists; the median noise estimate was 85dB(A) (range 60–97). Noise exposure estimates were made for 96% of the 24 860 person-years of employment for all subjects combined, the remainder being periods for which there were no job titles. Estimates were made from information in the noise survey reports for 65% of the total person-years, from additional rules for buildings not included in noise surveys for a further 16%, and on the basis of job titles only for a further 15%. In terms of subjects, 93% had noise estimates covering their whole period of employment. For the remainder, exposure in missing periods was inferred from the part of their employment that had noise estimates (see Methods). Noise estimation was more likely to be based directly on noise survey data at site A (79% of person-years) compared to site B (52% of person-years).

Sixty four per cent of subjects (n = 1402) were considered exposed—that is, they had a noise exposure of 85dB(A) or more for at least one year; the remaining subjects formed the ''unexposed'' group. Twenty six per cent (n = 583) had exposure for at least 10 years and 8% (n = 186) for at least 20 years. Among the exposed, 468, 469 and 465 were placed in ''Low'', ''Medium'', and ''High'' exposure groups respectively based on the NIL_{85} measure.

Baseline cardiovascular and other factors for exposure groups

The relation between exposure and the measured baseline cardiovascular risk factors, BP, BMI, height, and smoking is shown in table 2 for the control group, who represent the population base[15] in this design. In general the differences are very small; the biggest is between the prevalence of hypertension at pre-employment among the High exposure group (25%) and the Low exposure group (19%). Smoking data were more likely to be missing in the unexposed group, but among those with smoking data, there was little evidence that exposure was correlated with smoking behaviour. However there was a strong relation between length of employment and exposure, as might be expected when an exposure measure is partly based on duration. The large differences in employment duration between High and Low noise exposure groups are a reminder that, if there was another occupational risk factor for cardiovascular disease in this cohort, exposure to which also increased with length of employment, it would confound the noise/heart disease relation unless properly controlled.

There were some differences between subjects at the two sites. On average, employees at site A were two years older at the start of employment and the duration of employment was two years less. Eighty five per cent of employees at site A had smoking information compared to 65% at site B. More subjects were classified as exposed (72%) at site A compared to B (56%).

Association between cardiovascular mortality and noise exposure

The five cardiovascular risk factors at pre-employment—systolic and diastolic blood pressure, BMI, height, and smoking—all showed the expected relationships with mortality in regression analyses, with somewhat stronger relationships emerging from site A. There was no evidence of increased risk of cardiovascular mortality in shiftworkers (OR = 0.98 comparing shift and non-shift) and this variable was omitted from further analyses. In general, adjustment for the five cardiovascular variables did not greatly change the ORs for exposure: the overall OR for exposed versus

Table 3 Ischaemic heart disease mortality and noise exposure: odds ratio for exposed (⩾1 year at 85dB(A) or higher) *v* unexposed

	% Exposed				
	Cases	Controls	Crude OR	Adj* OR (95% CI)	Adj† OR (95% CI)
Both sites	65%	62%	1.14	1.15 (0.95–1.40)	1.13 (0.92–1.39)
Site A	72%	72%	1.00	0.95 (0.70–1.29)	0.99 (0.71–1.40)
Site B	59%	53%	1.26	1.32 (1.02–1.70)	1.25 (0.96–1.62)

*Model included five pre-employment measures: systolic and diastolic BP, BMI, smoking, and height.
†Model included five pre-employment measures and duration of employment.

Table 4 Ischaemic heart disease mortality and noise exposure at 85dB(A) or higher: odds ratios by years of exposure compared to unexposed

Years at ⩾85dB(A)	Crude OR	Adj* OR (95% CI)	Adj† OR (95% CI)
Both sites			
1–9.9	1.21	1.23 (0.99–1.52)	1.20 (0.96–1.49)
10–19.9	1.04	1.02 (0.78–1.33)	0.95 (0.70–1.30)
20+	1.11	1.07 (0.73–1.55)	0.98 (0.63–1.51)
Site A			
1–9.9	1.11	1.05 (0.75–1.46)	1.06 (0.71–1.51)
10–19.9	0.86	0.79 (0.53–1.16)	0.72 (0.44–1.19)
20+	0.88	0.81 (0.45–1.46)	0.70 (0.34–1.44)
Site B			
1–9.9	1.26	1.34 (1.00–1.78)	1.26 (0.95–1.70)
10–19.9	1.24	1.31 (0.88–1.93)	1.21 (0.80–1.83)
20+	1.29	1.22 (0.75–2.00)	1.17 (0.67–2.07)

*Model included five pre-employment measures: see table 3.
†Model included five pre-employment measures and duration of employment.

unexposed, adjusted for the five factors, was 1.15 (95% CI 0.95 to 1.40) compared to 1.14 when unadjusted (table 3). When the association was estimated separately for each site, no evidence of increased risk was found for site A (adjusted OR = 1.00), but at site B the OR was 1.32 (95% CI 1.02 to 1.70). When duration of employment was also included in the model, the latter reduced to 1.25 (95% CI 0.96 to 1.62). In what follows, ''adjusted ORs'' always indicates adjustment for the five cardiovascular risk factors only, unless further qualified. Results with further adjustment for duration of employment are also shown in tables.

There was no evidence of a trend with years of exposure above 85dB(A). In fact the highest ORs tended to be seen in those with 1–10 years of exposure (table 4) and, at site A, the ORs for those with more than 10 years exposure were less than 1. Tests of trend in risk with increasing years of exposure in the exposed group alone were carried out as described in the Methods. None of the trends was statistically significant: at site A the OR per 10 years of exposure above 85dB(A) was 0.84 (95% CI 0.67 to 1.05) and at site B, it was 1.01 (95% CI 0.82 to 1.24) (table 5).

The NIL_{85} measure, which combines duration with intensity of noise above 85dB(A), might be expected to show a stronger relationship than duration alone. Overall, there was no evidence (table 6) of an exposure-response relation for this variable: those in the High exposure category (NIL_{85} ⩾99.7) had almost the same risk (OR = 1.07, 95% CI 0.82 to 1.39) as the unexposed group. However, at site B, the ORs showed a pattern more consistent with an exposure-response relation, being 1.15 (95% CI 0.81 to 1.65), 1.45 (95% CI 1.02 to 2.06) and 1.37 (95% CI 0.96 to 1.96) for Low, Medium, and High categories respectively. With further adjustment for duration of employment, these dropped to 1.15, 1.32, and 1.31 respectively and none of these was significantly different from one (table 6). When a test of trend in risk with increasing values of the continuous measure, NIL_{85}, at site B was carried out, there was little evidence of a systematic trend: the adjusted OR associated with an increase of 5dB(A) in NIL_{85} was 1.03 (95% CI 0.86 to 1.22).

Duration of employment was investigated as an independent predictor of risk, after controlling for the five cardiovascular risk factors, and also with additional control for NIL_{85}. Those employed for less than five years were used as the baseline group. At site A, there was little evidence of a relation (table 7) but at site B, there was evidence of a non-linear trend: mortality rates from ischaemic heart disease were higher in those with at least five years' employment but with a smaller increase in those with very long employment.

Table 5 Ischaemic heart disease mortality and noise exposure at 85dB(A) or higher: odds ratios associated with each 10 years of exposure, assuming a constant trend in exposed group only*

	Crude OR	Adj† OR (95% CI)	Adj‡ OR (95% CI)
Both sites	0.96	0.94 (0.81–1.09)	0.91 (0.76–1.09)
Site A	0.85	0.84 (0.67–1.05)	0.79 (0.59–1.07)
Site B	1.06	1.01 (0.82–1.24)	1.02 (0.81–1.29)

*Model included dichotomous exposure variable (years at 85dB(A) or higher exposure)/10.
†Model included five pre-employment measures: see table 3.
‡Model included five pre-employment measures and duration of employment.

To investigate the possibility of a non-linear relation with duration at this site, a quadratic function of the continuous variable, employment duration, was fitted in the model instead, The quadratic term was statistically significant ($p = 0.047$), and the model coefficients suggested a peak in risk at approximately 20 years' employment. In the analysis with adjustment for NIL_{85} as well as the five cardiovascular risk factors, the p value for this term was 0.101.

If duration of employment is a proxy for some other exposure, then it is important that the estimates of noise effects are properly adjusted. As shown in table 2, duration of employment and cumulative exposure were strongly correlated; in fact 95% of those with Medium or High cumulative exposure were employed for more than five years compared to 33% of the unexposed group. In previous models (tables 3–6) where noise effects were ''adjusted'' for duration of employment, the models assumed that the effects of duration of employment and noise on risk combine multiplicatively. Arguably (see Discussion) a better analysis is to stratify by employment duration (<5 years, 5 years or more) and to compare noise exposure groups within each stratum, with a focus on those employed for longer. An analysis of this kind was carried out within the framework of a conditional logistic regression model. Among workers at site B with at least five years' employment, there were 211 unexposed subjects and 95, 186, and 218 subjects in the Low, Medium, and High categories of NIL_{85}; the ORs for the exposed categories compared to unexposed were 1.07 (93% CI 0.64 to 1.77), 1.33 (95% CI 0.88 to 2.01), and 1.21 (95% CI 0.82 to 1.79) respectively.

DISCUSSION

Interpretation of the results from this study is complicated by an apparent divergence between the results for the two sites.

Table 6 Ischaemic heart disease mortality and NIL_{85}: odds ratios for categories* of NIL_{85} versus unexposed

	Crude OR	Adj† OR (95% CI)	Adj‡ OR (95% CI)
Both sites			
Low	1.11	1.15 (0.89–1.47)	1.14 (0.89–1.47)
Med	1.24	1.23 (0.96–1.57)	1.18 (0.90–1.55)
High	1.08	1.07 (0.82–1.39)	1.03 (0.76–1.39)
Site A			
Low	1.08	1.04 (0.72–1.51)	1.04 (0.71–1.51)
Med	1.03	1.00 (0.69–1.46)	1.03 (0.65–1.60)
High	0.88	0.77 (0.52–1.14)	0.74 (0.44–1.22)
Site B			
Low	1.06	1.15 (0.81–1.65)	1.15 (0.80–1.65)
Med	1.46	1.45 (1.02–2.06)	1.32 (0.91–1.91)
High	1.27	1.37 (0.96–1.96)	1.31 (0.88–1.94)

*Low, 85–94.7; Med, 94.8–99.6; High, 99.7–110.8 dB(A)-years.
†Model included five pre-employment measures: see table 3.
‡Model included five pre-employment measures and duration of employment.

Table 7 Ischaemic heart disease mortality odds ratio by duration of employment and site

Years employed	n	Crude OR	Adj* OR (95% CI)	Adj† OR (95% CI)
Both sites				
<5	862	Baseline		
5–9.9	283	1.17	1.15 (0.84–1.58)	1.10 (0.79–1.54)
10–14.9	272	1.27	1.21 (0.86–1.71)	1.16 (0.80–1.68)
15–19.9	295	1.04	1.01 (0.71–1.45)	0.99 (0.66–1.47)
20–24.9	248	1.25	1.26 (0.86–1.83)	1.24 (0.82–1.89)
25+	242	1.08	1.04 (0.71–1.52)	1.04 (0.68–1.59)
Site A				
<5	468	Baseline		
5–9.9	143	0.87	0.86 (0.54–1.36)	0.87 (0.52–1.46)
10–14.9	138	1.05	0.98 (0.59–1.62)	1.08 (0.61–1.91)
15–19.9	142	0.80	0.77 (0.47–1.24)	0.89 (0.50–1.60)
20–24.9	117	1.05	1.03 (0.61–1.72)	1.24 (0.67–2.28)
25+	90	0.91	0.84 (0.47–1.49)	1.05 (0.53–2.07)
Site B				
<5	394	Baseline		
5–9.9	140	1.58	1.57 (1.00–2.46)	1.47 (0.93–2.32)
10–14.9	134	1.58	1.58 (0.97–2.59)	1.41 (0.84–2.35)
15–19.9	153	1.42	1.49 (0.86–2.58)	1.29 (0.72–2.30)
20–24.9	131	1.47	1.59 (0.91–2.79)	1.37 (0.75–2.50)
25+	152	1.23	1.27 (0.74–2.17)	1.10 (0.62–1.95)

*Model included five pre-employment measures and duration of employment.
†Model included five pre-employment measures, four-category NIL_{85} variable and duration of employment.

The validity of the retrospective noise estimation process is critical to interpretation. In a separate study,[14] we found that years of exposure above 85dB(A) and the NIL_{85} measure were predictive of hearing loss at site B, with a clear dose-response relation. However there was little evidence of predictive validity at site A. There are a number of possible explanations for this, including poor measures of hearing loss and/or poor estimation of noise at site A. One possibility, raised by a referee, was that inappropriate or inadequate adjustments for hearing protection when estimating noise dose might have distorted the relations at site A. If so, and there is a genuine effect of noise on cardiovascular risk, we might expect to see a stronger relation among the 350 case-control pairs at site A whose exposure histories preceded 1975: no adjustments for hearing protection were made before that date. In fact, the OR for exposed versus unexposed in this period, adjusted for the five risk factors, was 1.04 (95% CI 0.73 to 1.49) and there was no evidence of a dose-response relation. Whatever the reasons for the poor predictive validity at site A, it suggests that the results on the relation between noise and ischaemic heart disease deaths at that site might be unreliable. In what follows, we consider mainly site B.

The results at site B suggested an increased risk at medium and high levels of cumulative exposure: the adjusted ORs for these groups were 1.45 (95% CI 1.02 to 2.06) and 1.37 (95% CI 0.96 to 1.96) respectively. However, interpretation of the results from site B is complicated by an apparent relation between duration of employment and deaths from ischaemic heart disease. This trend could reflect the presence of another exposure at site B whose effects also increased with duration. However, we know of no other exposures at this workplace which could plausibly[16] be related to ischaemic heart disease, apart from shiftwork; in unpublished work, we found no relation with duration of shiftwork at this site. Another possible explanation for this trend is that it reflects a complicated employment selection process whereby those who leave the workforce within five years have *better* cardiovascular health than longer term employees, coupled with a healthy worker survivor effect in very long term employees. Our final analysis, which estimated noise effects from those with at least five years' employment, would overcome part of any such selection or confounding problem. The ORs from this analysis, 1.07, 1.33, and 1.22 for Low, Medium, and High categories of NIL_{85} respectively, were not statistically significant.

There is no consensus about noise threshold levels for cardioscular effects. Our choice of 85dB(A) as a threshold on our scale was based in part on opinions[6 7] that the threshold was at most 85dB(A), in part on our view that the hygienists' assessments were unlikely to be underestimates, and in part to allow comparability with another occupational study[5] which used this same threshold. For comparison, it is useful to note that 20 years' exposure at a level of 85dB(A) would give a NIL_{85} of 98 dB(A)-years, which is at the upper end of our Medium category. The ORs here for Medium and High groups are of a similar magnitude to the OR of 1.3 reported by Davies[5] for workers with 20 years exposure at levels of 85dB(A) or higher. However, although suggestive of a trend, our results do not provide clear evidence of an exposure effect. One possible explanation is lack of statistical power: although the overall study power was adequate to detect relative risks of the order of 1.3 or greater, the power for separate site analyses was much reduced.

Possible mechanisms whereby noise might induce cardiovascular effects have been described and are based on activation of the sympathetic and/or endocrine systems.[17] Authors have considered the possibility that effects might be seen only in those annoyed by noise, in which case subjective assessment of noise might be a better predictor than objective measures; however, in studies with objective and subjective measures, the former performed better.[17] Nevertheless, sensitivity to noise might induce some workers to change their jobs, leaving a healthy subgroup who are better able to cope. If true for our cohort, such a phenomenon, akin to the healthy worker survivor effect, would mean that noise dose-response relations would be flattened.[18] We have not attempted to correct for any such survivor effects.

General strengths of the study methodology, applicable to both sites, should be noted. The study was confined to industrial workers and thus there was a form of indirect matching for those cardiovascular factors that tend to vary by social class. There seemed little difference between noise groups for those risk factors that were measured at pre-employment at an average age of 38 years. Confounding is still possible if exposed and unexposed men went on to develop a different pattern of exogeneous risk factors, but it

seems unlikely that a large difference would have emerged. In assessing noise exposure, study hygienists had no access to information that could identify subjects and therefore noise assessment was blind to group (case/control) status.

An important limitation is that the study estimated noise exposure only while employed by a single company, rather than lifetime exposure. Workers could have been exposed to high noise in other jobs or in the general environment or through hobbies. Both sites, but especially B, were in a relatively sparsely populated part of the UK where urban noise—from traffic, aircraft, etc—was probably not high. Duration of exposure to noise via hobbies seems unlikely to be high, and occasional high intensity exposure from hobbies is unlikely to be important. However exposure to noise through other jobs seems likely; the proportion of the total noise burden which is missing from our cumulative noise measures is likely to be greater for short term employees. These considerations further support the restriction of the analysis to those with longer employment. Ideally we would have restricted by duration of employment still further, but the numbers were too small.

Overall, the strength of this study, beyond the obvious advantages of longitudinal studies, is that it is accompanied by substantial information about the strength of the exposure assessment. Many commentators[19–21] in occupational epidemiology have drawn attention to the difficulties of retrospective exposure assessment and its validation. Here the incorporation of a validation study has added substantially to the quality of the evidence on the association between noise and cardiovascular mortality at site B. Given that noise levels still exceed 85dB(A) in many industries,[22] further longitudinal research is undoubted needed.

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